# THE FEASIBILITY OF SOLAR ENERGY APPLICATION TO COMMUTER RAIL CAR HEATING AND AIR CONDITIONING

prepared by

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## 1. Introduction

This investigation was conducted in order to determine the feasibility of heating and air conditioning a commuter rail car by utilizing energy supplied by solar energy collectors mounted on the car.

For this purpose, a literature search was undertaken to determine the amount of incident solar radiation per $ft.^2$ in New Jersey and to find the most promising solar energy utilization techniques for this application.

Background information on solar energy, and collection and conversion methods is first presented. This is followed by a determination of the percentage of the heating and air conditioning requirements of a commuter rail car that could be supplied by solar energy on an hourly basis for June 21st and December 21st. June 21st is the day of the year which would normally receive the greatest amount of daily solar radiation, and December 21st would normally receive the least. Finally, the cost of the solar energy utilization techniques that were considered is briefly examined - a rigorous cost analysis not being realistic at this time.

For this study, the heating and air conditioning requirements specified for the 70 General Electric commuter rail cars ordered in 1973 by the NJDOT, and intended for operation by Penn Central are considered.

Two types of solar energy collectors are discussed: (1) silicon solar cells and (2) flat-plate collectors - fundamentally, a box designed to trap heat by minimizing heat losses to its surroundings. The energy provided by silicon solar cells is used in conjunction

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Two types of solar energy collectors are discussed: (1) silicon solar cells and (2) flat-plate collectors - fundamentally, a box designed to trap heat by minimizing heat losses to its surroundings. The energy provided by silicon solar cells is used in conjunction

with electrical resistance heating and mechanical compression air conditioning, and the energy provided by flat-plate collectors, with hot water heating and absorption air conditioning.

## 2. Conclusions

The first three conclusions apply to the General Electric commuter rail car ordered in 1973 by NJDOT.,

2.1 Silicon solar cell collecting arrays used in conjunction with a mechanical compression air conditioner, and electrical resistance heating could provide approximately 9.2% of the air conditioning requirement and 2.7% of the heating requirement for the best hour of a typical June 21st and December 21st, respectively.

2.2 Flat-plate solar energy collectors used in conjunction with an absorption air conditioner, and an adapted hot water heating system could provide approximately 11.5% of the air conditioning requirement and 12% of the heating requirement for the best hour of a typical June 21st and December 21st, respectively.

2.3 If collected solar energy is used to partially replace the electrical energy now needed to air condition or heat the G. E. car on June 21st or December 21st, a maximum cost reduction of less than \$1.00 a day can be obtained at the present time. Currently, the average cost of electrical energy to heat and air condition one of Patco's commuter rail cars is approximately \$12.00 a day.

2.4 In light of the foregoing conclusions and the cost analysis presented hereinafter, utilizing the energy supplied by car-mounted solar collectors to heat and air condition a commuter rail car seems only remotely feasible. Whether an overall energy savings can be realized by car-mounted collectors is questionable. Although the collected

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IV. Conclusions

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1. Optimum solar cell collecting arrays used in conjunction with a mechanical compression air conditioner, and electrical resistance heating could provide approximately [illegible]% of the air conditioning requirements and [illegible]% of the heating requirements for the west wing of a typical one floor and basement [illegible], respectively.

2. Flat-plate solar energy collectors used in conjunction with an absorption air conditioner and an absorption hot water heating system could provide approximately [illegible]% of the air conditioning requirements and [illegible]% of the heating requirements for the west wing of a typical one floor and basement [illegible], respectively.

3. If a [illegible] solar array is used to partially replace the electrical energy now supplied to air conditioners and [illegible] at [illegible], a net annual energy reduction of more than [illegible] a day can be achieved at the [illegible]. Currently, the average cost of electrical energy to heat and air condition [illegible] is approximately [illegible] a day.

4. In light of the foregoing conclusions and the cost analysis, one [illegible] that using solar energy [illegible] collectors [illegible] at this time [illegible] only [illegible]. [illegible] all energy systems can be evaluated [illegible] is questionable. Although the evidence

solar energy could partially replace electrical energy normally consumed in heating and air conditioning the car (energy savings), additional energy would be required by the propulsion system in order to maintain the same specifications with the additional weight of collectors (energy loss).

In order to more exactly determine the cost and benefits of this solar energy application and to decide whether a significant energy savings can be realized, a more complete study would have to be undertaken.

## 3. Discussion

### 3.1 Background

#### 3.1.1 Amount of Solar Energy

The amount of solar energy that reaches the earth in a day is dependent mainly upon (1) the length of sunlight periods, (2) solar altitude (height of the sun above the horizon), and (3) the condition of the atmosphere.

The length of sunlight periods and the solar altitude depend on the season of the year and latitude. The period of sunshine can range from 9 hours in the winter to 15 hours in the summer for New Jersey's latitude. Solar altitude varies with the time of the day and solar radiation on a horizontal surface is greatest when the sun is highest.

Atmospheric conditions can range from clear skies to cloudy skies with "industrial atmospheres". Solar radiation is reflected, scattered, and absorbed by air molecules, dust, water vapor and man-

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Atmospheric conditions may range from clear skies to cloudy skies with "industrial atmosphere". Solar radiation is reflected, scattered, and absorbed by air molecules dust, water vapor and ozone,

made pollution. Their combined effect can reduce the solar energy transmitted through the atmosphere by more than one third.

The intensity of solar radiation on a surface depends upon how that surface is oriented in relation to the sun's rays. It is a maximum when a surface is perpendicular to the direction of the sun's rays, and decreases correspondingly as the angle between the surface and the sun's rays differ from perpendicularity.

### 3.1.2 Solar Energy Collection and Conversion

The six types of solar energy collection and conversion methods discussed are (1) solar cells, (2) flat-plate collectors, (3) focusing collectors, (4) thermoelectric conversion, (5) thermionic conversion, and (6) photo-chemical conversion.

#### 3.1.2.1 Solar Cells - Photovoltaic Cells

Solar cells convert light energy from the sun directly into electrical energy. In the process, no consumption or cycling of material is required. The cells are composed of two layers of semi-conductor material - each layer is a different type - separated by an "electrical barrier" at their junction. In these devices absorption of light generates free electrical charges which can be collected on contacts applied to the surfaces of the semi-conductors. See Figure 1, p. 5.

Of the different types of solar cells, silicon cells have yielded the best efficiencies. The average efficiency of present production cells is 13 to 14% for terrestrial application.[9] Due to transmission losses from glassing, space losses in packing due to geometry, and parallel-series resistance effects, etc., commercially

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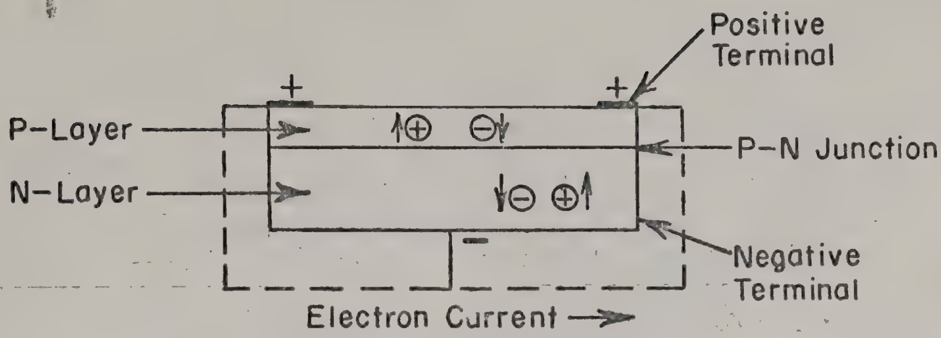



ARRANGEMENT OF SOLAR CELL

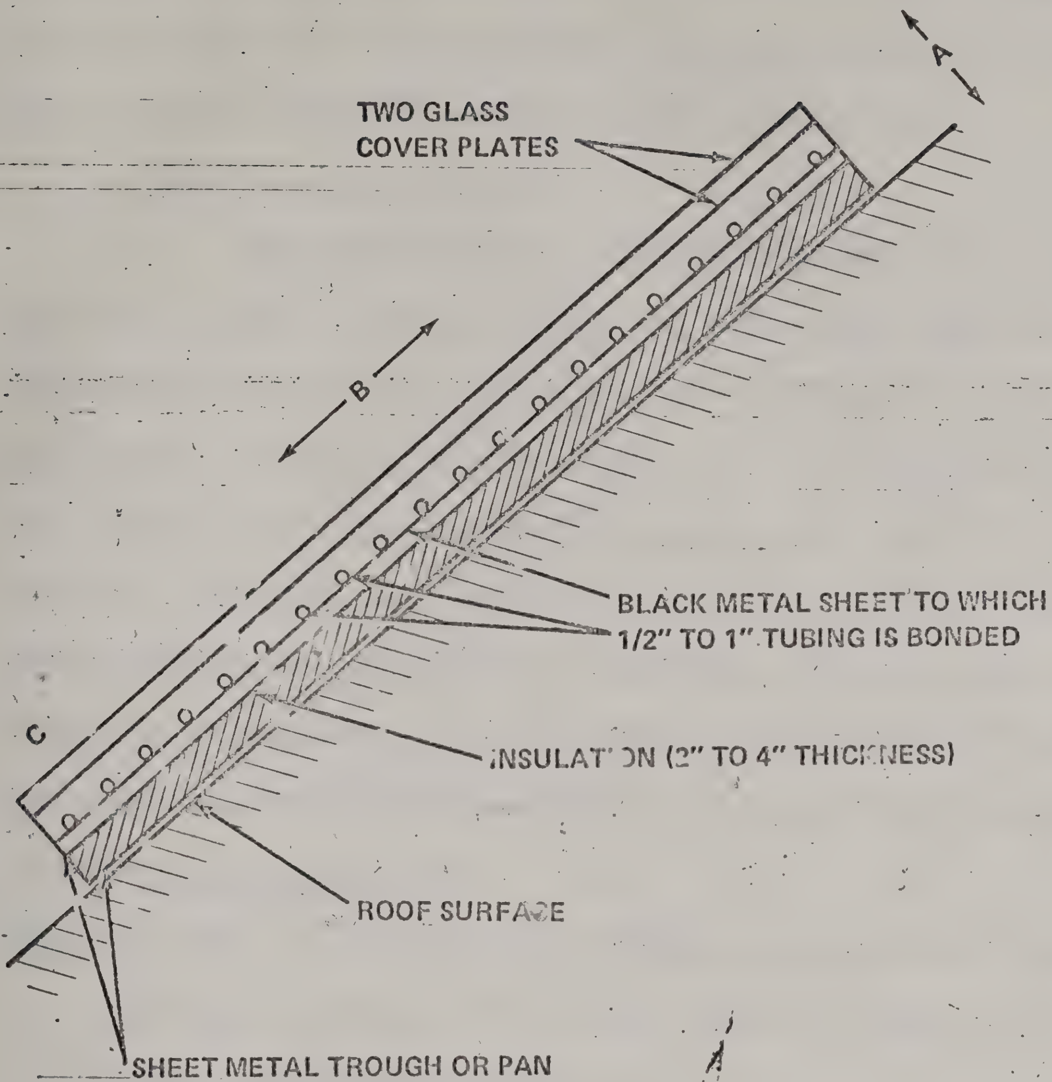
FIGURE 1

available solar cell arrays have effective efficiencies on the order of 5%.

3.1.2.2 Flat-Plate Collectors

This is the primary type of solar collector which has been used in the heating and cooling of buildings over the last 30 years. A common type consists of a metal plate which is painted black (to improve heat absorption) on the side facing the sun and thermally insulated on the edges and on the back side. Figure 2, p. 6. Above the absorbing plate, spaced a 1/2 inch or so apart, are one or more glass or plastic surfaces to reduce upward heat losses. Thus, flat-plate collectors retain energy in a heat trap so that the heated object (absorber plate) does not loose its heat too rapidly. Collected energy is removed by circulating water in tubes in thermal contact with the absorbing plate. A similar type of collector can be used with air as the heat transfer medium. The collector outlet temperature of water or air is in the range of 90-220°F.

In building application, the collectors are usually titled at an angle of 10 to 15° + latitude from the horizontal. Peak efficiencies of 50% have been achieved in many installations.[3]




NOTES: ENDS OF TUBES MANIFOLDED TOGETHER
ONE TO THREE GLASS COVERS DEPENDING ON CONDITIONS

DIMENSIONS: THICKNESS (A DIRECTION) 3 INCHES TO 6 INCHES
LENGTH (B DIRECTION) 4 FEET TO 20 FEET
WIDTH (C DIRECTION) 10 FEET TO 50 FEET
SLOPE DEPENDENT ON LOCATION AND ON WINTER-SUMMER LOAD COMPARISON

FLAT-PLATE SOLAR COLLECTOR USED FOR RESIDENTIAL HEATING AND COOLING

FIGURE 2

Flat-plate collectors can effectively collect heat from diffuse solar radiation (reflected from other surfaces) as well as direct solar radiation, and can operate on bright cloudy days.

3.1.2.3 Focusing Collectors

Focusing collectors concentrate energy from a large area on to a small heating surface. The most common types are parabolic mirrors and lens arrangements. See Figure 3, p. 8. Much higher temperatures can be obtained with these collectors and they offer a distinct advantage for operating heat engines (a mechanism for converting heat energy into mechanical energy). However, focusing collectors require direct sunlight, a cloudless sky, and automatic sun-tracking equipment. The main application of focusing collectors has been in the area of solar furnaces where temperatures of 6000°F have been achieved.

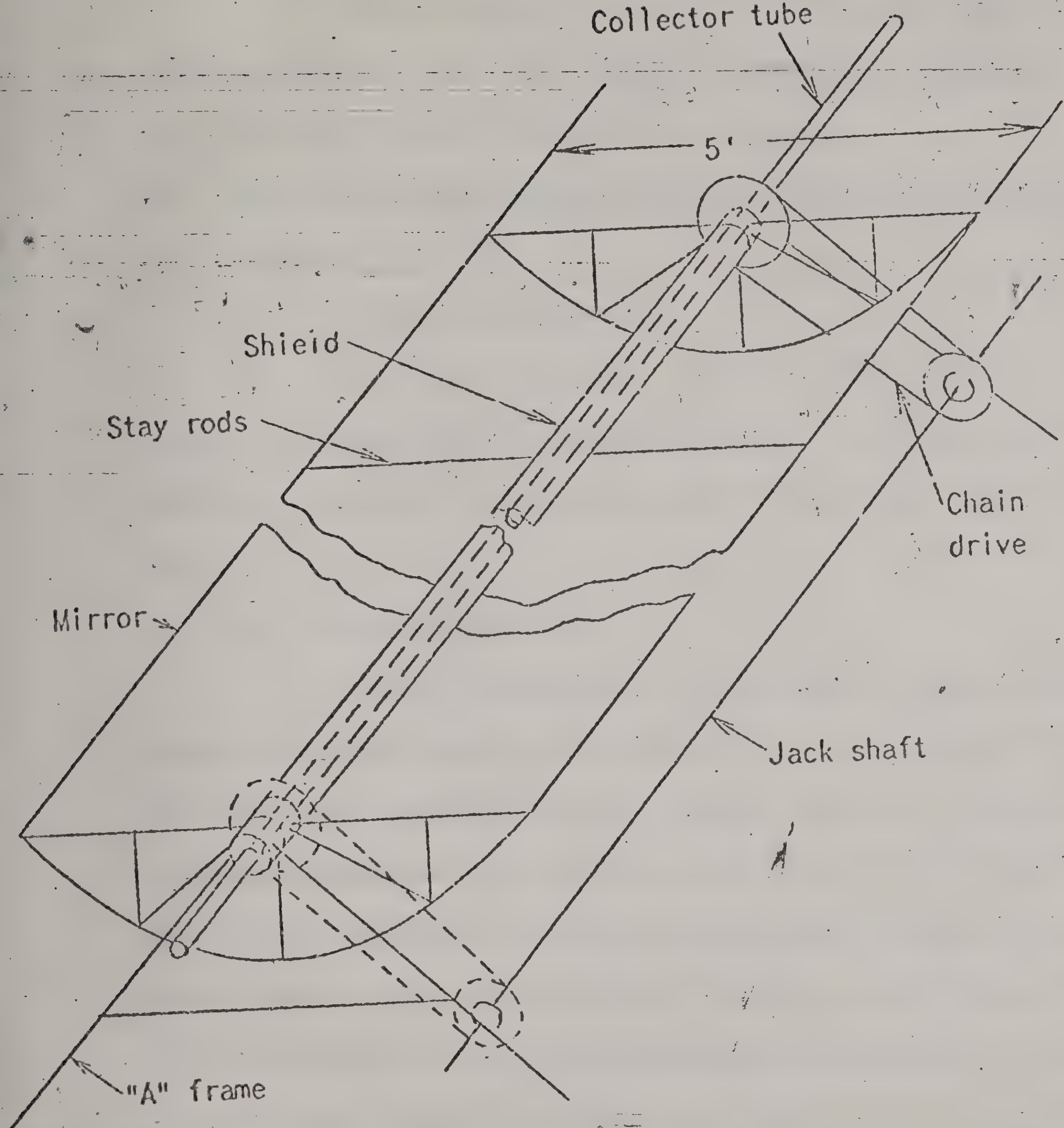
Note: In solar application, the following three methods of conversion have achieved efficiencies of on the order of 5%.[10]

3.1.2.4 Thermoelectric Conversion

Thermoelectric conversion makes use of the thermocouple effect - two junctions of dissimilar metals in series will develop a voltage (and associated current) proportional to the temperature difference of the junctions. In solar application thermoelectric generators have been used with both flat-plate and focusing collectors.

3.1.2.5 Thermionic Conversion

In thermionic converters an electron-emitting surface is employed. It must be heated to temperatures of 2700°F or above. Thermionic converters have only been used with focusing collectors




SCHEMATIC OF A SIMPLE FOCUSING COLLECTOR

FIGURE 3

due to the very high temperatures required.

3.1.2.6 Photo-Chemical Conversion

Photo-chemical conversion utilizes the light energy of solar radiation. This light energy is directly absorbed by molecules of a substance and can thereafter be recovered.

## 3.2 Solar Energy Application to Commuter Rail Car Heating and Air Conditioning

### 3.2.1 Car Under Consideration

As already mentioned, the rail car considered in this discussion is manufactured by General Electric. In dimension, it is 85 feet long, 10 feet, 6 inches wide, and 15 feet high. See Figure 4, p. 10.

### 3.2.2 Energy Collection

In constructing a rail car that would utilize solar energy, energy collectors could be located on the top and sides of the car. The top should receive relatively constant sunshine, however, solar radiation which could be received by the sides would in many instances be blocked by trees and buildings alongside the tracks and would depend heavily upon which direction the car was traveling. Because it is not possible to accurately determine the amount of this side-incident solar radiation without a much more in depth analysis, side-mounted collectors are not considered further. Energy collectors located on the front and back of the car would not be worthwhile since they would not receive sufficient solar radiation. Thus, only solar energy collection from the top of the car is considered.

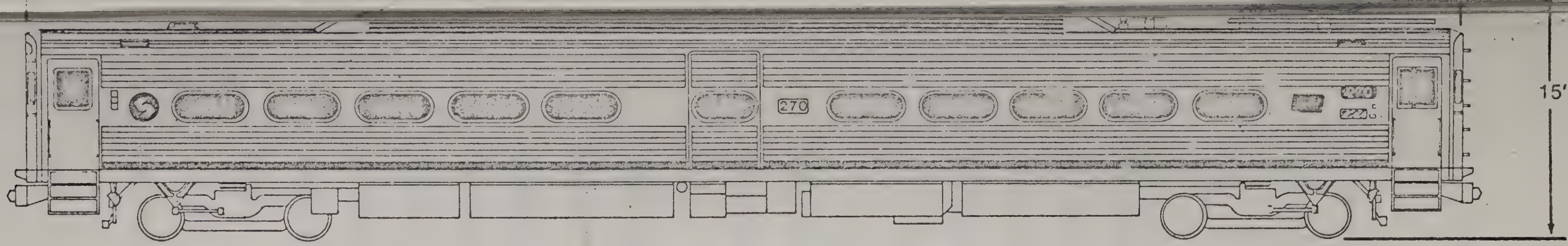



FIGURE 4



# SEPTA/NJDOT Car Information

| | |
|---|---|
| Customer | Southeastern Pennsylvania Transportation Authority and New Jersey Department of Transportation |
| Number of cars | 214 (144 SEPTA and 70 SONJ) |
| Passengers (Seated) | 129 SEPTA, 100/96 SONJ |
| Passengers (Maximum Load) | 250 |
| Car Length | 85′ |
| Car Width | 10′6″ |
| Car Height | 15′ |
| Power | AC 11 KV, 25 Hz; 25 KV, 60 Hz Catenary |
| Braking | Combination dynamic and air |
| Maximum Speed | 100 mph |
| Construction | Stainless Steel |

General Electric transportation systems

TRANSIT SYSTEMS PRODUCTS DEPT.
ERIE, PENNSYLVANIA 16501

GENERAL ELECTRIC

GEA-9924 (2.5M) 8-73

3.2.2.1 Collection Area Available

The area of the top is 893 square feet of which 500 sq. ft. is assumed available for collectors since the remaining area is used for the pantograph and other roof-mounted equipment.

3.2.2.2 Collector Position

For this investigation collectors located on the top of the car are assumed to be fixed in a horizontal position. Whether tilted collectors would offer an advantage might best be determined experimentally - once again the changing orientation of a rail car in motion makes analysis extremely difficult.

3.2.3 Incident Solar Radiation

Incident solar radiation levels used in this investigation were derived from references to graphical data presented by I. F. Hand of the U. S. Weather Bureau, Milton, Massachusetts. See Figure 5 & 6, p. 12. Notice that the data is for a horizontal surface, clear day, and latitude 42°N for a typical June 21st and December 21st. Discounting cloud cover, June 21st is the day of the year which would normally receive the most solar radiation on a horizontal surface and December 21st would normally receive the least. Incident radiation levels in the State of New Jersey (latitudes 39°-41° 30') are expected to be close in value to these. This particular solar data was used because it was the most complete hour by hour information that was found.

Values derived from these graphs and adjusted for annual mean cloudiness for 42°N latitude are shown in the center column of

Incident Solar Energy on a Horizontal Surface

clear days, latitude 42°N

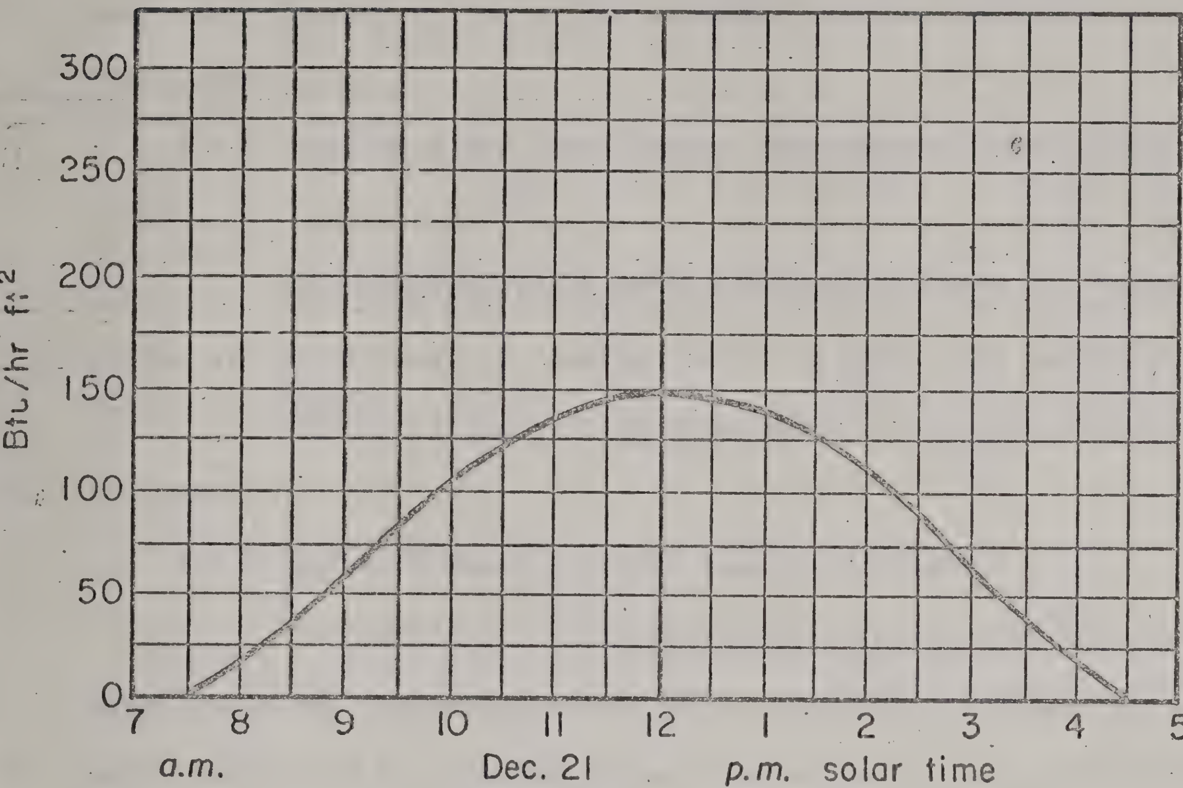



FIGURE 5

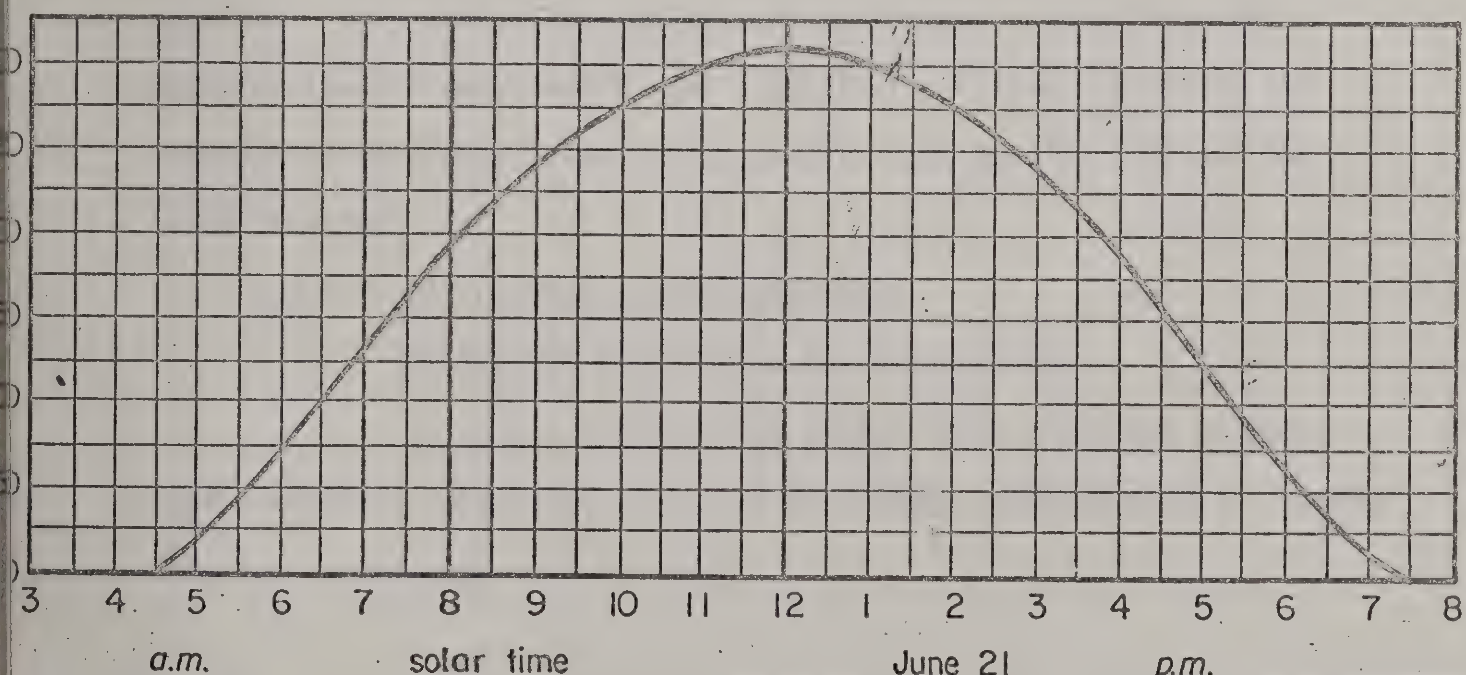



FIGURE 6

Tables 1 and 2, pgs. 14 and 15.* The center column was multiplied by 500 to obtain the right hand column. Thus the amount of solar radiation per hour that would be incident on 500 ft.$^2$ of horizontal solar collectors located on top of the commuter rail car is given in this right hand column.

### 3.2.4 Heating & Air Conditioning Requirements of the General Electric Car

The specifications of the General Electric car indicate a 14 ton air conditioner is required which is equivalent to 168,000 BTUH.

The specified heating requirement is 31 kilowatts or 105,000 BTUH.

### 3.2.5 Selected Means of Solar Energy Utilization

Two methods of solar energy utilization were considered in determining the percentage of the air conditioning and heating requirements that could be supplied by car mounted solar energy collectors because they were found to be the most efficient and the most widely applied. They are silicon solar call collectors used with mechanical compression air conditioning and electrical resistance heating, and flat-plate collectors used with absorption air conditioning and hot water heating.

#### 3.2.5.1 Silicon Solar Cell Collectors

Mechanical Compression Air Conditioning

In an air conditioning system using these two components, the electrical power from the solar cell array would be used to operate the air conditioner.

*On the average 25% of the incoming solar radiation is reflected to space by clouds (latitude 42°N).[6]

TABLE 1

Solar Radiation Incident On

Commuter Rail Car's 500 ft.$^2$ of Collector Area

June 21

| Solar Time | Incidence on Horizontal Surface $(\frac{BTUH}{ft^2})$ | Incidence on Collector Area (BTUH) |
|---|---|---|
| 4:30 - 5:30 A. M. | 18.75 | 9,375 |
| 5:30 - 6:30 A. M. | 56.25 | 28,125 |
| 6:30 - 7:30 A. M. | 99 | 49,500 |
| 7:30 - 8:30 A. M. | 146.25 | 73,125 |
| 8:30 - 9:30 A. M. | 180 | 90,000 |
| 9:30 - 10:30 A. M. | 210 | 105,000 |
| 10:30 - 11:30 A. M. | 228.75 | 114,375 |
| 11:30 - 12:30 P. M. | 238.5 | 119.250 |
| 12:30 - 1:30 P. M. | 226.5 | 113,250 |
| 1:30 - 2:30 P. M. | 210 | 105,000 |
| 2:30 - 3:30 P. M. | 180 | 90,000 |
| 3:30 - 4:30 P. M. | 142.5 | 71,250 |
| 4:30 - 5:30 P. M. | 97.5 | 48,750 |
| 5:30 - 6:30 P. M. | 52.5 | 26,250 |
| 6:30 - 7:30 P. M. | 15 | 7,500 |

TABLE 2

Solar Radiation Incident On

Commuter Rail Car's 500 ft.$^2$ of Collector Area

December 21

| Solar Time | Incidence on Horizontal Surface $\left(\frac{BTUH}{ft^2}\right)$ | Incidence on Collector Area (BTUH) |
|---|---|---|
| 7:30 - 8:30 A. M. | 15 | 7,500 |
| 8:30 - 9:30 A. M. | 46.5 | 23,250 |
| 9:30 - 10:30 A. M. | 78.75 | 39,375 |
| 10:30 - 11:30 A. M. | 102.75 | 51,375 |
| 11:30 - 12:30 P. M. | 112.5 | 56,250 |
| 12:30 - 1:30 P. M. | 105 | 52,500 |
| 1:30 - 2:30 P. M. | 84 | 42,000 |
| 2:30 - 3:30 P. M. | 52.5 | 26,250 |
| 3:30 - 4:30 P. M. | 15.0 | 7,500 |

Currently manufactured silicon solar cell arrays have a collection efficiency of approximately 5%. In other words, the energy output of the collector is 5% of the solar energy incident on the collector.[11]

Mechanical compression air conditioners contain a compressor, evaporator, expansion valve, and condenser through which a refrigerant such as "Freon" is circulated. Heat is absorbed by the refrigerant at the evaporator and given off at the condenser. The air conditioner with which this car is normally equipped is of this type. The coefficient of performance (C.O.P.) of this type of unit is about 2.6.[12] Consequently, with 1.0 BTUH of input power the unit will remove 2.6 BTUH of heat from the cooled space. Thus, in order to meet the air conditioning requirement of the car (168,000 BTUH), a mechanical compression air conditioner would require a power input of about 64,600 BTUH.

When used from hereon, the overall efficiency of a method of solar energy utilization means the percentage of the solar energy incident on the collector which can be realized as either air conditioning or heating.

The overall efficiency of this method is approximately equal to the product of the collector efficiency and the air conditioner C.O.P. or (5%) x (2.6) = 13.0%. The amount of air conditioning that can be provided and the percentage of the air conditioning requirement of the rail car which can be supplied on June 21st are shown in the right center and far right columns of Table 3, p. 17, respectively.

TABLE 3

Solar Cell Collector

&

Mechanical Compression Air Conditioning

Assumed Overall Efficiency = 13.0%

Air Conditioning Requirement = 168,000 BTUH

June 21

| Solar Time | Incidence on Collector Area (BTUH) | Air Conditioning Provided (BTUH) | % of A. C. Requirement Supplied |
|---|---|---|---|
| 4:30 - 5:30 A. M. | 9,375 | 1,219 | 0.7 |
| 5:30 - 6:30 A. M. | 28,125 | 3,658 | 2.2 |
| 6:30 - 7:30 A. M. | 49,500 | 6,435 | 3.8 |
| 7:30 - 8:30 A. M. | 73,125 | 9,506 | 5.7 |
| 8:30 - 9:30 A. M. | 90,000 | 11,700 | 7.0 |
| 9:30 - 10:30 A. M. | 105,000 | 13,650 | 8.1 |
| 10:30 - 11:30 A. M. | 114,375 | 14,869 | 8.9 |
| 11:30 - 12:30 P. M. | 119,250 | 15,503 | 9.2 |
| 12:30 - 1:30 P. M. | 113,250 | 14,723 | 8.8 |
| 1:30 - 2:30 P. M. | 105,000 | 13,650 | 8.1 |
| 2:30 - 3:30 P. M. | 90,000 | 11,700 | 7.0 |
| 3:30 - 4:30 P. M. | 71,250 | 9,263 | 5.5 |
| 4:30 - 5:30 P. M. | 48,750 | 6,338 | 3.8 |
| 5:30 - 6:30 P. M. | 26,250 | 3,413 | 2.0 |
| 6:30 - 7:30 P. M. | 7,500 | 975 | 0.6 |

Electrical Resistance Heating

For this method, the electrical power obtained from the solar cell array would be used to power resistance heating elements.

The overall efficiency of the method would be about 5%.

Table 4, p. 19 indicates the amount of heating that could be provided and the percentage of the heating requirement supplied by this method on a typical December 21st.

3.2.5.2 Flat-Plate Collectors

Absorption Air Conditioning

The type of air conditioning unit normally used with flat-plate collectors is the absorption type. Absorption air conditioning is suited for use with these collectors because it can be hot water - powered and thus can make the most direct use of the hot water collector output.

Horizontal flat-plate solar collectors used in conjunction with absorption air conditioners would be expected to have maximum efficiencies of 30%. This efficiency is somewhat lower than normal flat-plate collector efficiency (40-50%) because of the higher collector outlet temperatures needed for the absorption cycle (175°F and up). Collector efficiency would be further reduced when the rail car is in motion due to increased wind speed across the top of the car. A vehicle speed of 30-60 miles per hour would reduce collector efficiency by an estimated ten percent - from 30 to 27%.

As with mechanical compression air conditioning, absorption air conditioning makes use of the evaporation and condensation of a refrigerant liquid, these processes occuring at two pressure

TABLE 4

Solar Cell Collector

&

Resistance Heating

Assumed Overall Efficiency = 5%    Heating Requirement = 105,000 BTUH

December 21

| Solar Time | Incidence on Collector Area (BTUH) | Heating Provided (BTUH) | % of Heating Requirement Supplied |
|---|---|---|---|
| 7:30 - 8:30 A. M. | 7,500 | 375 | 0.4 |
| 8:30 - 9:30 A. M. | 23,250 | 1,163 | 1.1 |
| 9:30 - 10:30 A. M. | 39,375 | 1,969 | 1.9 |
| 10:30 - 11:30 A. M. | 51,375 | 2,569 | 2.4 |
| 11:30 - 12:30 P. M. | 56,250 | 2,813 | 2.7 |
| 12:30 - 1:30 P. M. | 52,500 | 2,625 | 2.5 |
| 1:30 - 2:30 P. M. | 42,000 | 2,100 | 2.0 |
| 2:30 - 3:30 P. M. | 26,250 | 1,313 | 1.3 |
| 3:30 - 4:30 P. M. | 7,500 | 375 | 0.4 |

levels within the unit. The two methods differ in that the absorption cycle uses a heat-operated generator to produce the pressure differential where the mechanical compression cycle uses a compressor. Lithium bromide-water and ammonia-water absorption air conditioning are the most common. The coefficient of performance (C.O.P.) of most absorption air conditioners is about 0.6.[3]

When a flat-plate collector is used in combination with an absorption air conditioner, the collector provides the heat to operate the generator. Figure 7, p. 22, illustrates this type of system.

The overall efficiency of a flat-plate collector-absorption air conditioning system would be approximately equal to the product of collector efficiency and air conditioner C.O.P. or (30%) x (0.6) = 18.0%. For a vehicle traveling at 30-60 mph, the effect of the wind could reduce the overall efficiency to (27%) x (0.6) = 16.2%.

Table 5, p. 21, indicates the amount of air conditioning that could be provided by this method and the percentage of the air conditioning requirement of the car which could be supplied on a typical June 21st.

Absorption air conditioners are generally sensitive to tilting and in this application the swaying of the commuter rail car could cause operational problems.[17]

Hot Water Heating

With this method, water heated from thermal contact with the absorber plate of the solar collector, is circulated to the space to be heated.

TABLE 5

Flat-Plate Collector

&

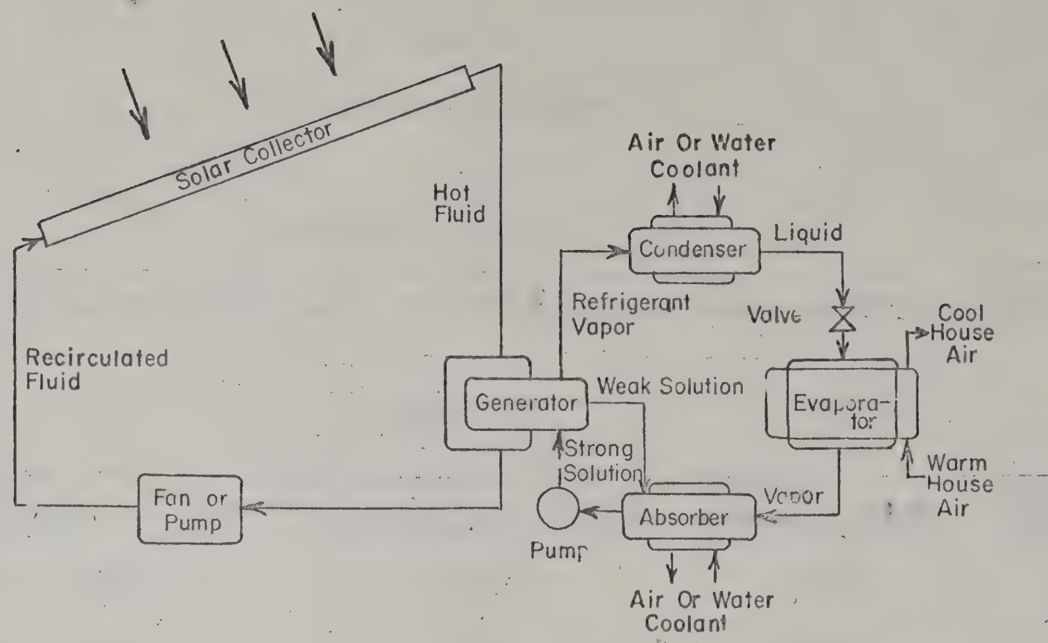
Absorption Air Conditioning

Overall Efficiency of 16.2% Assumed

Air Conditioning Requirement = 168,000 BTUH

June 21

| Solar Time | Incidence on Collector Area (BTUH) | Air Conditioning Provided (BTUH) | % of A. C. Requirement Supplied |
|---|---|---|---|
| 4:30 - 5:30 A. M. | 9,375 | 1,519 | 0.9 |
| 5:30 - 6:30 A. M. | 28,125 | 4,556 | 2.7 |
| 6:30 - 7:30 A. M. | 49,500 | 8,019 | 4.8 |
| 7:30 - 8:30 A. M. | 73,125 | 11,846 | 7.1 |
| 8:30 - 9:30 A. M. | 90,000 | 14,580 | 8.7 |
| 9:30 - 10:30 A. M. | 105,000 | 17,010 | 10.1 |
| 10:30 - 11:30 A. M. | 114,375 | 18,529 | 11.0 |
| 11:30 - 12:30 P. M. | 119,250 | 19,319 | 11.5 |
| 12:30 - 1:30 P. M. | 113,250 | 18,347 | 11.0 |
| 1:30 - 2:30 P. M | 105,000 | 17,010 | 10.1 |
| 2:30 - 3:30 P. M. | 90,000 | 14,580 | 8.7 |
| 3:30 - 4:30 P. M. | 71,250 | 11,543 | 6.9 |
| 4:30 - 5:30 P. M. | 48,750 | 7,898 | 4.7 |
| 5:30 - 6:30 P. M. | 26,250 | 4,253 | 2.5 |
| 6:30 - 7:30 P. M. | 7,500 | 1,215 | 0.7 |




SOLAR COOLING BY ABSORPTION AIR CONDITIONING

FIGURE 7

In wintertime the maximum collection efficiency of a horizontal flat-plate collector is approximately 25%.[13] For a vehicle moving at from 30-60 m.p.h., the wind effect would reduce this by ten percent to about 22.5%. With piping losses minimal, the overall efficiency of this method is 22.5%.

Table 6, p. 23, indicates the amount of heating provided by this method, and also the percentage of the heating requirement supplied.

Flat-plate collector-hot water heating systems are most commonly used in the heating of buildings. A combination solar hot water heating and cooling system for a building is shown in Figure 8, p. 24. A hot water storage tank is normally incorporated into the system in order to store heat during hours when the solar heating supplied

TABLE 6

Flat-Plate Collector

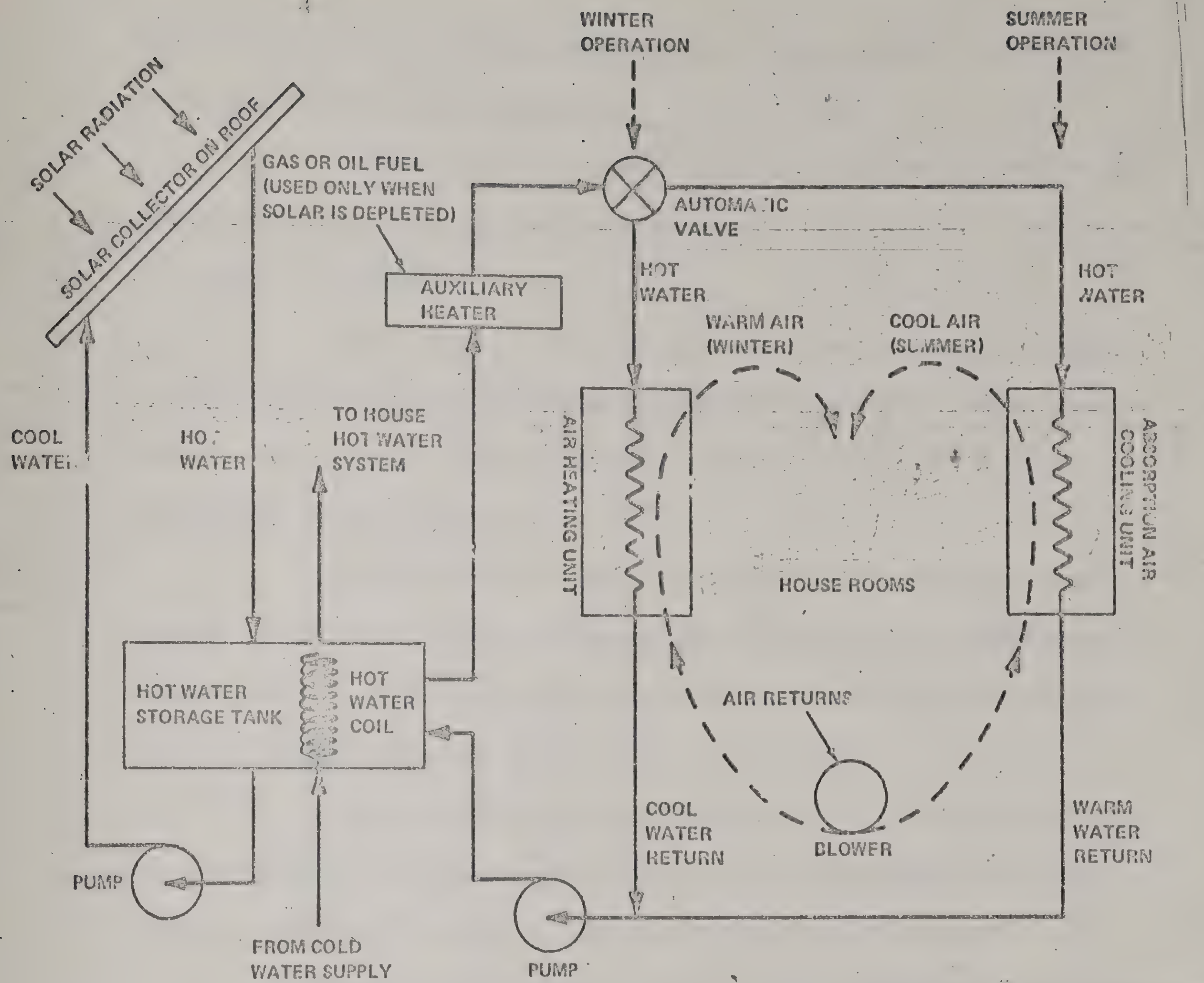
&

Hot Water Heating

Assumed Overall Efficiency = 22.5%  Heat Requirement = 105,000 BTUH

December 21

| Solar Time | Incidence on Collector Area (BTUH) | Heating Provided (BTUH) | % of Heating Requirement Supplied |
|---|---|---|---|
| 7:30 - 8:30 A. M. | 7,500 | 1,688 | 1.6 |
| 8:30 - 9:30 A. M. | 23,250 | 5,231 | 5.0 |
| 9:30 - 10:30 A. M. | 39,375 | 8,859 | 8.4 |
| 10:30 - 11:30 A. M. | 51,375 | 11,559 | 11.0 |
| 11:30 - 12:30 P. M. | 56,250 | 12,656 | 12.0 |
| 12:30 - 1:30 P. M. | 52,500 | 11,813 | 11.2 |
| 1:30 - 2:30 P. M. | 42,000 | 9,450 | 9.0 |
| 2:30 - 3:30 P. M. | 26,250 | 5,906 | 5.6 |
| 3:30 - 4:30 P. M. | 7,500 | 1,688 | 1.6 |




RESIDENTIAL HEATING AND COOLING SYSTEM

FIGURE 8

is in excess of the buildings requirement. Stored heat is later used during the night or cloudy periods.

For the case of the rail car, no excess solar heating can be supplied and heat storage is not necessary.

3.2.5.3 Summary

Tables 3, 4, 5 & 6 indicate that the maximum percentage of the air conditioning requirement of the rail car that can be supplied by the selected air conditioning methods is on the order of 10-12% on a typical June 21st.

Likewise, these same tables show that the maximum percentage of the heating requirement of the car that can be supplied by the more efficient of the selected heating methods is on the order of 12% on a typical December 21st.

The maximum energy supplied by any of the selected solar energy utilization methods occurs at solar noon, and the energy supplied decreases as the time of the day varies from solar noon.

During no hour was the instantaneous heating or cooling requirement met by any of the selected means of solar energy utilization.

In applying any of the selected methods, therefore, solar power could only supplement, during periods of sunshine, the primary heating and air conditioning system of the car.

If solar cell collectors were mounted on the G. E. car, their output (electrical power) could be utilized by the air conditioning and heating systems with which the car is normally equipped. Thus the primary heating and air conditioning of the car would be accomplished in the customary way and merely supplemented by solar power.

On the other hand, if flat-plate collectors were mounted on the G. E. car, their output (hot water) would not be readily compatible with the existing heating and air conditioning systems of the G. E. car. If the existing heating and air conditioning were used, additional equipment to convert the energy in the hot water to electrical energy would be required. Thus, the primary heating and air conditioning would be achieved as usual and supplementary solar energy would be supplied by flat-plate collectors and energy conversion equipment. A more efficient approach would be to use an air conditioning and heating system what would be readily compatible with the hot water output of the collectors. Such a system could be hot water heating and absorption air conditioning. A hot water-operated absorption air conditioner would replace the mechanical air conditioner with which the existing car is equipped and hot water heating would replace the resistance heating. The primary heating and air conditioning requirements of the car would be met by the electrical power with which the car is normally supplied, and supplemented by solar power when available.

3.2.6 Cost of Solar Energy Application to Commuter Rail Car Heating and Air Conditioning

The specifications for the G. E. Commuter rail car now call for electrical resistance heating and mechanical compression air-conditoning.

The cost of obtaining an operational solar energy utilization system in a commuter rail car would depend on whether existing cars are modified or whether new cars are designed with consideration of solar energy utilization in the pre-fabrication stage. In either case, these types of costs can be expected: (1) engineering costs (design, drawings,

specifications, etc.), (2) cost of materials, (3) installation cost, (4) operational cost, and (5) maintenance cost. Because of the uniqueness of this solar energy application, these cost figures are not readily available. However, the cost of materials used in other solar energy applications, primarily the heating and cooling of buildings, are known, and are presented in order to give the approximate cost of materials for this application.

For a solar heating and air conditioning system composed of silicon solar cells, resistance heating, and mechanical compression air conditioning, the major cost of materials would be about \$47,000 for the 500 $ft^2$ solar cell array (as indicated by Spectrolab, Division of Textron), and (2) \$5,600 for a 14 ton mechanical compression air conditioner (Transport Refrigeration Division, Carrier Corporation).

For a solar heating and air conditioning system composed of flat-plate collectors, hot water heating, and hot water-powered absorption air conditioning, the major cost of materials would be about (1) \$3,450 for 500 $ft^2$ of flat-plate collectors @ \$6.50 per square foot (Pittsburgh Plate Glass Industries), and (2) \$8,000 for an absorption air conditioner capable of supplying 15 tons of cooling in this application (Arkla Air Conditioning, Inc.).

The reduction in electrical energy costs for heating and air conditioning the car which could be realized by utilization of solar energy is presented in Table 7, p. 28.

Table 7

| Date | Method | Electrical Energy Replaced | Cost Reduction |
|---|---|---|---|
| June 21 | Silicon Solar Cells & Mech. Compression A.C. | 15.5 kw-hr | $0.62 |
| December 21 | Silicon Solar Cells & Resistance Heating | 4.5 kw-hr | $0.18 |
| June 21 | Flat-Plate Collector & Absorption A.C. | 19.3 kw-hr | $0.77 |
| December 21 | Flat-Plate Collector & Hot Water Heating | 20.3 kw-hr | $0.81 |

In the above table, the cost reduction is estimated on a per car basis for a typical June 21st and December 21st. In determining the dollar amounts in this table, an electrical power charge of 4.0¢ per kilowatt hour was used. (This is the approximate rate that Public Service charges Patco for electrical power for the Lindenwold High Speed Line). Table 7 shows that the maximum cost reduction for electrical energy for any of these methods on June 21st or December 21st is less than $1.00 per car.

Currently, the average cost of electrical energy to heat and air condition Patco's commuter rail cars is estimated at $12.00 a day per car. This estimate is based on Patco's average daily service of 5 hours per car, a 200 car-mile day, a power consumption for heating and air conditioning of 1.5 kilowatt-hours per car-mile, and an electrical power charge of 4.0¢ per kilowatt-hour.

# SOURCES OF INFORMATION

## Reference Texts


1. Bryson, Frederick E., "Plugging Into the Sun", Machine Design, February 7, 1974, pps. 20-25.
2. Daniels and Duffie, "Solar Energy Research", University of Wisconsin Press, .. 1955.
3. Zarem, A. M. & Erway, D. D., "Introduction to the Utilization of Solar Energy", McGraw-Hill, c. 1963.
4. "A Sunny Outlook for Solar Power", IEEE Spectrum, April 1974, pps. 76-77.
5. "Heating, Ventilating, & Air Conditioning Guide 1954", The American Society of Heating and Ventilating Engineers, Vol. 32.
6. Seymour, L. S., "Introduction to Theoretical Meterology", Holt, Rinehart & Winston, Inc., 1959.
7. Marks Standard Handbook for Mechanical Engineers, Seventh Edition, McGraw-Hill, c. 1967.
8. "Proceedings of the Solar Heating and Cooling for Buildings Workshop", National Science Foundation - Research Applied to National Needs, March 21-23, 1973.
9. "Solar Energy as a National Energy Resource", NSF/NASA Solar Energy Panel, December 1972.
10. Daniels, F., "Direct Use of the Sun's Energy", Yale University Press, 1964.

## SOURCES OF INFORMATION

### Industry

11. Derived from information from:
Mr. Don Simon, Spectrolab, a Division of Textron Inc. via Bartlett Associates, 130 W. Lancaster Avenue, Wayne, Pa.

12. Messrs. Frank Nini & John Vegas, Trane Air Conditioning Inc., Princeton, N. J.

13. Mr. P. Richard Rittlemann, National Science Foundation Solar Energy Panel-Space Conditioning, Architect, Burt, Hill, and Associates, Butler, Pa.

14. Mr. R. R. Lewchuk, Pittsburgh Plate Glass Industries, Pittsburgh, Pa.

15. Mr. Bowkley, The Budd Company, Philadelphia, Pa.

16. Mr. Michael Cifrese, Transport Refrigeration Division, Carrier Corporation, Syracuse, N. Y.

17. Mr. Dana Gibson, Arkla Air Conditioning, Little Rock, Arkansas.

18. Mr. Glenn Merrill, Honeywell, Inc., Minneapolis, Minnesota.

19. Mr. W. F. Moore, General Electric, Space Systems Organization, King of Prussia, Pa.

20. Mr. J. W. Vigrass, Port Authority Transit Corporation, Bridge Plaza, Camden, N. J.